



THE WIND ENGINEER

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Citizen Sensing for a Resilient World

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Despite an increasingly sophisticated understanding of how wind interacts with bridges and buildings, data to support and advance the theory is notoriously fragmented and scarce. Wind-related natural hazards cause billions of dollars in property damage annually, and have devastating impacts on human lives all over the world. To inform wind-resilient design and construction, a sophisticated understanding of how structures are behaving in wind is crucial. However, executing full scale monitoring projects is complex and expensive and frustratingly subject to the whims of Nature. Even a perfectly executed monitoring project can fail if the wind decides not to blow in the right place at the right time. After all, the reach of wind engineering researchers is limited to the temporal and geographic boundaries of their monitoring equipment. Or is it? In the face of growing threats from wind-related disasters, building by building and bridge by bridge studies are wholly inadequate to address the urgent need to build systemically resilient communities. Wind Engineers are uniquely positioned to harness the untapped power of every-day citizens and the technology in their pockets to make breakthrough progress in the understanding of the interaction between wind and structures.

Smart phones in the hands of non-experts have incredible potential to revolutionize timely access to massive amounts of information about the built environment and the wind hazards that effect it. From disaster reconnaissance to insights on skyscraper serviceability to the dynamic investigation of lively bridges, information derived from built-in smart phone technology is ripe for the picking.

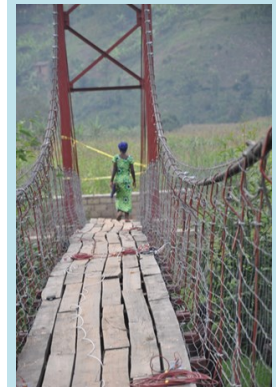
Rural Footbridge Monitoring Program

One particularly powerful example of citizen sensing is the use of built-in smart phone accelerometers to collect essential dynamics data from wind-sensitive footbridges. A simple dynamic testing procedure has been developed to understand the dynamic behavior of a widely built wind-sensitive standardized footbridge design to identify vulnerability to dynamic wind action and inform the development of wind-resistant options. The efficacy of smart phone technology in captur-

ing footbridge dynamics was validated by testing the phones alongside industry standard sensing system from Bridge Diagnostics, Inc.(BDI). Nexus 4 smartphones proved very accurate in identifying bridge frequencies and damping ratios from free decay acceleration signals instigated by a rope plucking the bridge deck. The instrumentation set-up is shown in Figure 1, where three smart phones were tested alongside a BDI sensing system. The figure also shows spectra resulting from the BDI system alongside results from the smart phones for a lateral and vertical pluck test.

A set of three Nexus 4 smartphones also showed promise in characterizing mode shapes, overcoming the obstacle of time synchronization using wavelet transforms to extract a specific frequency and then using the cross-correlation of the signals to achieve time synchronicity in post processing. Figure 2 shows the free decay signal from the three smart phones and a representation of the signal in the time-frequency domain along with the extracted signal corresponding to a single mode. The raw time histories of all three phones are plotted in the top right, and below them the automatically time synchronized signals.

To date, dynamics data has been collected from 18 footbridges in Nicaragua, Rwanda, Panama, Bolivia and Haiti, and this number is expected to grow substantially as the citizen sensing movement gains momentum in this sector. A world leader in rural footbridge technology which publishes a standard suspension footbridge design manual which is built in more than 16 countries around the world recently committed to incorporate a smart phone dynamics data protocol into their as-built reporting requirements. In addition to providing invaluable data about individual footbridges being built across the globe, this commitment will offer unprecedented access to aggregated dynamics information from scores of



Muregeya Footbridge, Rwanda



International Association
for Wind Engineering

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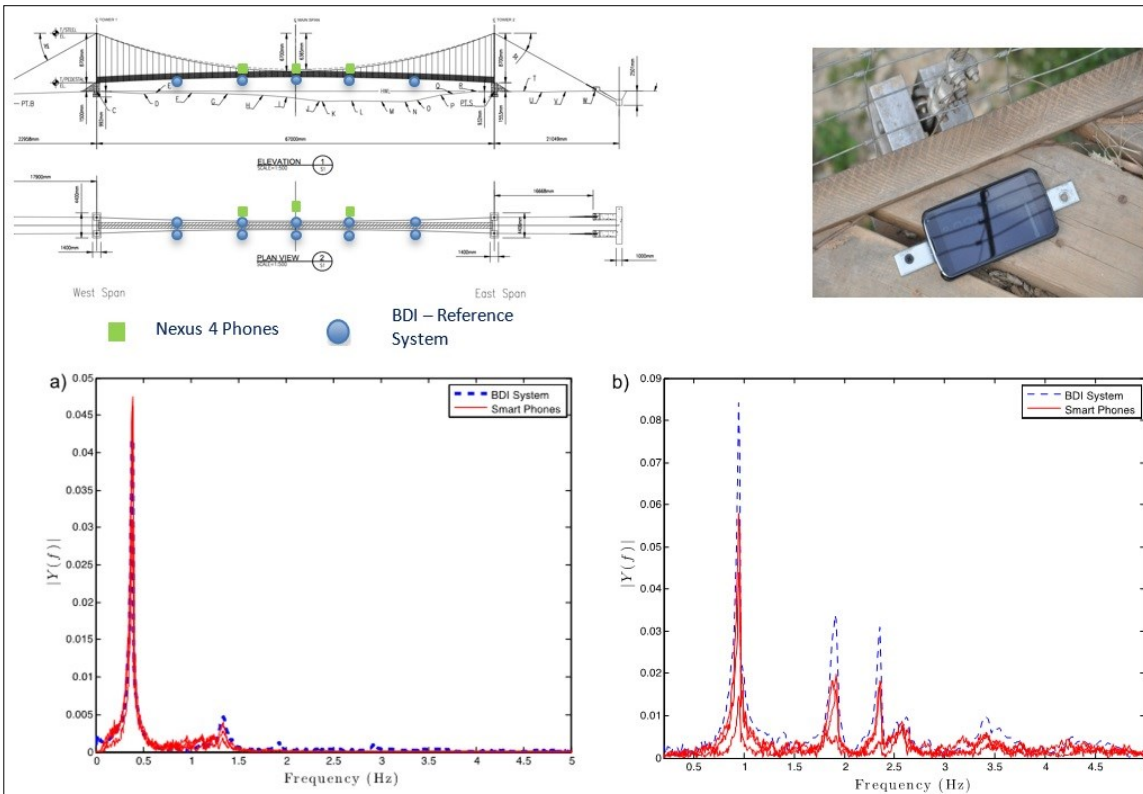


Figure 1. Comparison of Smart Phones to Industry Standard sensing system.

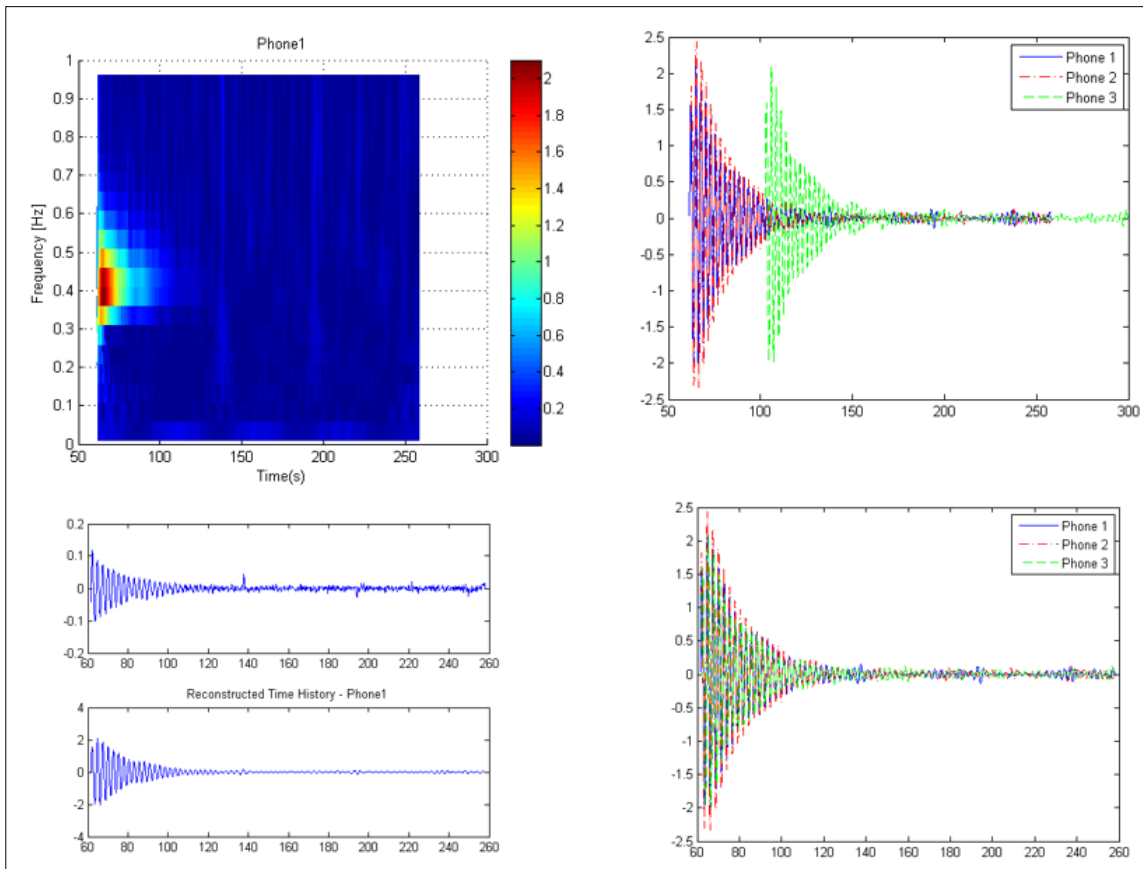


Figure 2. Automatic time synchronization of smart phone signals.

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new footbridges annually, facilitating the development of insights about underlying system behavior between small variations in projects. This will provide an exciting opportunity to explore fundamental structural contributions to critical dynamics data. Additionally, a citizen sensing army will be deployed across

the globe, ready to spring into action when a wind event strikes a footbridge. In a matter of minutes, a smart phone can be attached to the bridge deck and record the response of the structure to the wind event. Citizen sensing provides an expansive network of eyes and ears capable of capturing valuable structural response information from unpredictable wind events.

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Moving Beyond Individual Structures

Current best practices for designing structures to resist dynamic wind effects require extensive structure-specific analysis, including detailed finite element modeling and often costly and time consuming wind tunnel experiments. As citizen sensing opens the door to a database of footbridge dynamic characteristics and responses to wind events we are faced with an opportunity to draw insights about dynamic footbridge behavior and develop the ability to predict the dynamic performance of cable-supported footbridges based on basic design inputs like span, tower height, sag ratio, etc. absent of a detailed bridge specific analysis. This progress has huge implications for footbridge construction, particularly in resource-constrained environments in the developing world. Where long span cable-supported footbridge projects used to be prohibitively costly and beyond the capabilities of municipal government engineers due to requirements for detailed dynamic analyses, citizen sensing is beginning to offer an alternative solution. Making inferences from dozens of existing cable-supported footbridges structures, engineers can predict their dynamic behavior of proposed footbridges and proceed with a wind-resistant design at sites where a few years earlier, a footbridge project would have been impossible. Citizen sensing is responsible for pushing forward rural footbridge technology to create life-changing access by connecting severely isolated communities to health clinics, schools and economic opportunities.

As the citizen sensing movement grows, there is an increasing need for post-processing methods which can accurately and rapidly process large quantities of data without individualized attention to each unique data set. Two automatic procedures have recently been developed which can be applied to free vibration responses or ambient vibration data sets which are accurate for both stationary and non-stationary signals with no manual manipulation required. The first is a wavelet transform, transformed singular value decomposition Laplace method while the second is a wavelet based spectral method. These procedures and others like them will be crucial and transforming the massive data sets which result from citizen sensing into knowledge that can be used to inform wind-resistant designs.

Conclusion

People are walking around with the technology to assess the health and safety of the structures they interact with each day, and people are not only willing to accept the role of citizen sensor, in fact they seek it out. A recent workshop on citizen sensing on rural footbridges at the annual Bridge Builder Conference in Estes Park, CO was overflowing, with several dozen eager individuals excited to learn the power of the sensor in their pocket. So much of a citizen's interaction with their infrastructure is shrouded in uncertainty and 'other-ness' that the opportunity to be an active participant in their surroundings appeals widely to people from all walks of life. It is this curiosity which is essentially human which is at the root of the power of the citizen sensing movement. The joy of discovery is no longer in the hands of those that have formal engineering training. In fact, the advancement of science knowledge in the field of wind engineering is quite literally laying dormant in the hands of average citizens all over the world. A simple app and a small nudge is all it takes to transform that potential into vast databases of data which can be drawn upon on an unprecedented scale to allow researchers



**Paso Real Footbridge,
Nicaragua**

to draw insights that will allow for the development of resilient communities.

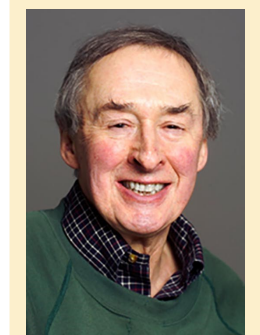
Acknowledgements

This project is supported by the National Science Foundation Graduate Research Fellowship. The smart phone app used in this study was developed by the modeling and simulation of structures group at Bauhaus University, Germany and additional support was provided by the University of Notre Dame.

A turbulence expert passes away

Ahsan Kareem

Professor **John L. Lumley**, the Willis H. Carrier Professor Emeritus of Mechanical and Aerospace Engineering, Cornell University who made seminal contributions to engineering in the study of turbulent fluid flow, died May 30, he was 84. Those of us in wind engineering owe debt to Prof. Lumley as we were introduced to turbulence by his book, "A First Course in Turbulence," along with others. During my doctoral research, I read several of his papers and other books like "The Structure of Atmospheric Turbulence."



Prof. John L. Lumley

His papers taught me POD now almost ubiquitous in every paper dealing with a fluctuating pressure or velocity field. It was pleasure meeting with him at CSU Fluid Mechanics Seminar Series as such opportunities are very inspiring for young students.

Lumley's theoretical contributions that are key to our modern knowledge of turbulence include statistical processes, the identification of structures in turbulence, the cascade dynamics of turbulence, and modeling of generic fluid flows, such as jets and wakes and turbulent flows near walls. In particular, he pioneered the use of "proper orthogonal decomposition" in turbulent flows. Although turbulent flows appear to be random, they also have structures. Professor Lumley was a member of the National Academy of Engineering.

AWES Workshop in Wine Country

Leighton Cochran

The 18th Australasian Wind Engineering Society Workshop will be held from 05-09 July 2016. The venue will be at McLaren Vale (close to Adelaide) in the heart of the South Australian wine country (Aussie version the Napa Valley). The venue will be the Serafino Convention Centre (www.serafinowines.com.au). Make your plans to head south, attend this traditional AWES event, and explore Australia at the same time. This event is deliberately a small, friendly, event with no parallel sessions – you get to see it all. Interaction is encouraged and it is an ideal venue for both graduate students and more seasoned researchers to present and explore all wind-engineering topics. The AAWE Workshops in the US were modelled on this low-key ambience and style. More information to come as 2016 approaches. Put on your calendar and we will see you there!



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